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W. B. CANNON, M.D.
George Higginson Professor of Physiology, Harvard University
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THE FUNCTIONS OF THE LARGE INTESTINE *

W. B. CANNON, M.D.
George Higginson Professor of Physiology, Harvard University
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The portion of the alimentary canal in which the final processes of normal digestion occur, and in which almost all the digested food is absorbed, is the small intestine. At the lower end of this long tube is the large intestine, serving as a reservoir to receive, store and periodically discharge the accumulation of waste. Mixed with the waste received in the large intestine is a slight amount of food which has hitherto escaped absorption; and if the diet has contained much vegetable substance, a good deal of cellulose may also be present. Throughout the small intestine the contents are maintained in a semifluid state — a state favorable to the energetic chemical processes which the food there undergoes, and favorable also to ease of movement through the canal and to readiness of absorption. The material delivered to the colon is still semifluid.

In the cecum and ascending colon the stagnant mixture of indigestible matter, food, cellulose, water and bacteria presents an ideal condition for putrefactive and fermentative decomposition. Indeed, Folin and Denis have recently shown that ammonia in the portal blood arises to a large degree in the colon[1] in which there is an abundance of ammonia developed from bacterial putrefaction. In this first part of the large intestine the last of the food disappears, the cellulose may undergo changes which result in its being utilized by the body,[2] and the water content begins to be reduced. Since no provision is made for continuance of important digestive processes in the colon and since very little available food

* Read in the Section on Surgery of the American Medical Association, at the Sixty-Third Annual Session, held at Atlantic City, June, 1912.

1. Folin and Denis: Jour. Biol. Chem., 1912, xi, 162.
2. Zuntz and Ustjanzev: Arch. f. Physiol., 1905, p. 403.

is carried there from the small intestine, the main functions of the colon are those of storage and periodic riddance of waste — both mechanical functions.

The absorption of water causes the consistency of the waste to be gradually more dense. Whereas the content of the cecum and ascending colon is soft and mushy, the content of the transverse colon may be found as firm as that which is discharged through the rectum.[3] This difference in consistency of the material in the proximal and in the distal colon corresponds to a difference in motor activity in these two regions.

MOVEMENTS OF THE PROXIMAL COLON

In 1902 I reported that in the proximal colon of the cat the characteristic movement is antiperistalsis,[4] or more briefly, anastalsis, a movement of waves backward toward the cecum.[5] In the distal colon, on the contrary, the firmer material is gripped by persistent rings of tonic constriction.

Anastalsis.—The anastaltic waves rarely run continuously for a long time. A series of waves, at the rate of about five per minute, can occasionally be seen running for four or five minutes and then ceasing. It is important to note that the waves start at the nearest ring of constriction. The condition for their appearance is normally the pushing of a fresh mass of material from the small intestine into the colon. This addition to the colonic contents results in a contraction of the proximal colon and a distention of the constriction ring. Recently I have presented evidence that the stretching of the ring of constriction causes it to pulsate, and that each pulsation sends off an anastaltic wave—a local response of the neuromusculature of the intestinal wall.[6] The distention of the colon by rectal injection will usually occasion the appearance of a long succession of these backward-moving undulations.

These *x*-ray observations on anastalsis of the cat's proximal colon were confirmed, in 1904, by Elliott and Barclay-Smith, who studied the activities of the large bowel exposed under warm salt solution. They also observed the activity in the rat and guinea-pig, and to some extent in the rabbit, hedgehog and ferret.[7] In the

3. Roith: Merkel and Bonnet's Arbeiten, 1903, xx, 32.
4. Cannon: Am. Jour. Physiol., 1902, vi, 265.
5. Cannon: Am. Jour. Physiol., 1912, xxx, 126.
6. Cannon: Am. Jour. Physiol., 1911, xxix, 238.
7. Elliott and Barclay-Smith: Jour. Physiol., 1904, xxxi, 272.

herbivorous animals which they studied, they found that sacculation of the proximal colon was associated with kneading movements, each sacculus becoming at times the seat of swaying oscillations. Indeed, there was a direct correlation between the degree of this kneading motion and the degree of sacculation of the wall.

The Question of Anastalsis in the Human Colon.—The colon of man is sacculated as in herbivores, rather than cylindrical as in carnivores. The question has arisen, and has stimulated a good deal of argument and observation, as to whether anastalsis occurs in the colon of man.

From the soft homogeneous nature of the contents of the proximal colon Elliott and Barclay-Smith assumed that in man the material is here "still delayed by a backward current, still commingled by the activity of the walls of the sacculi."

Inferential evidence for anastalsis in the human proximal colon has been drawn from cases of cecal fistula. In these cases rectal enemas have been observed to traverse the entire length of the colon and to escape through the artificial opening. In such cases also, surgeons have attempted to stop the fecal discharge by transplanting the ileum into the transverse colon, but the discharge continued. F. T. Murphy and others have reported cases of this character.[8] Maucaire has described an instance of persistent fecal discharge from a fistula in the cecum after the ileum had been sewed into the lower end of the descending colon; the backward transport of material ceased only when the colon was cut across and closed above the new ileocecal junction.[9] This reversed current is certainly consistent with effective anastalsis in man.

A variety of *x*-ray observations also have been interpreted as indicating anastalsis in the human proximal colon. Thus Stierlin found that the cecum and near-by colon retain longer than any other part of the alimentary canal the mixture used to produce *x*-ray shadows.[10] Furthermore, the sacculi or haustra are in this region often absent or only slightly developed. Bloch[11] and von Bergmann and Lenz[12] have seen in man, by means

8. Murphy, F. T.: Boston Med. and Surg. Jour., 1911, clxiv, 154.
9. Maucaire: Cong. franç. de chir., Paris, 1903, p. 86.
10. Stierlin: Ztschr. f. klin. Med., 1910, lxx, 392.
11. Bloch: Med. Klin., 1911, vii, 219.
12. von Bergmann and Lenz: Deutsch. med. Wchnschr., 1911, xxxvii, 1425.

of the *x*-rays, the contents of the cecum and ascending colon quickly forced onward to the beginning of the transverse colon; and then after a short period a definite retrograde movement of the contents which again filled the proximal portion.[13] This to-and-fro shifting may recur rhythmically for some time, and, although appearing spontaneously, can be stimulated by palpation. Von Bergmann and Lenz have suggested that the backward movement, or "retrograde transport," of the contents may result simply from relaxation of the proximal portion, after the contraction which forced the material onward. They admit, however, that this return may be hastened by contraction of the transverse colon.

Although the escape through cecal fistulas of material introduced distally into the colon clearly demonstrates a backward current in the human large intestine, although the long retention of material in the cecum is good evidence of retarded progress, and although the retrograde transport of material in the proximal colon can be interpreted as due to a backward pressure, nevertheless these facts do not prove the presence of anastalsis, in the sense of visible waves passing backward over the intestinal contents. And Hertz has testified to having watched with the *x*-rays the shadows of the human colon for various periods in a large number of individuals without seeing the phenomenon. Even the introduction of an enema (containing bismuth) under a pressure which rendered the entire colon visible, did not call forth any anastaltic activity.[14] Rieder† has recently been able to bring evidence, however, on the basis of his *x*-ray studies, that anastalsis actually does occur in the human colon. While it appeared in the main along the cecum, ascending and proximal transverse colon, it might appear in any portion of the large intestine. These observations on man are wholly in accord with those of myself and Elliott and Barclay-Smith on lower animals.

As will be recalled, the anastaltic waves start in the cat at the tonically constricted ring nearest the cecum. Furthermore, they can be started in the inactive intestine by making a tonic ring. The tonic ring is therefore of prime importance in originating anastalsis.

13. I have seen the same phenomenon in the cat. (Cannon: The Mechanical Factors of Digestion, London and New York, 1911, p. 160.)

14. Hertz: Constipation and Allied Intestinal Disorders, London, 1909, p. 7.

† Rieder: Fortschr. a. d. Geb. d. Röntgenstrahlen, 1912, xviii, 118.

Now, Boehm has recently described human cases in which the *x*-rays have revealed a narrowing of the transverse colon usually situated at the right of the mid-line, with undivided contents between it and the cecum, and with permanently segmented masses between it and the sigmoid flexure.[15] As Boehm noted, the narrow place is similar to the first tonic ring observed in cats, which served as the source of anastaltic waves. Injection of the human colon under these conditions might evoke these waves.

Haustral Churning. — On the basis of Elliott and Barclay-Smith's testimony that kneading or mixing contractions of the colonic walls are specially notable when sacculi or haustra are well developed, the human colon should be expected to manifest such activities. According to Schwarz's *x*-ray studies on man,[16] such haustral changes are occurring constantly. He refers to these changes as due to peristalsis, but his figures and his statement that the changes are strictly local depressions of the contour, now here, now there, suggest that he was actually watching haustral contractions, which are in fact not unlike the rhythmic segmentation of the small intestine. Rieder also has seen these oscillations of the haustra, and has revived for them the undescriptive term, "pendulum movements."

Whether the predominant movements of the proximal colon are extensive contractions shifting the mass of contents rhythmically forward and back, as von Bergmann and Lenz observed them (the large "pendulum movements" of Rieder), or gentle compressions of the contents of the sacculi, as Schwarz has noted, the effect must be, in either case, a thorough mixing and overturning of the material in this region, and an exposure of the semifluid mass to the absorbing mucosa. This first portion of the large intestine should be regarded, therefore, as a place in which digestion and absorption might still continue.

MOVEMENTS OF THE DISTAL COLON

The distal colon, which, on the basis of Roith's studies, may be regarded as beginning in man roughly near the middle of the transverse portion, contains normally firm and formed masses of waste material. In this region the characteristic activity of the intestinal

15. Boehm: Deutsch. Arch. f. klin. Med., 1911, cii, 444.
16. Schwarz: München med. Wchnschr., 1911, lviii, 1489.

wall is an onward-moving wave, or diastalsis. There is indeed some evidence that difference in the direction of waves is dependent on the consistency of the contents. Thus in the rat the proximal colon is the seat of anastaltic waves if the contents are soft and moist, but exhibits the diastaltic reflex if the material is stiff and dry.

Diastalsis.—Two modes of advancing the contents of the distal colon have been observed in man. Holzknecht has recorded having seen, by means of a fluorescent screen, the contents of one section of the colon moved onward into an empty distal section by a sudden push lasting only a few seconds. The haustral segmentation disappeared just before the advancement began, but reappeared at once when the material became settled in its new position. The function of the haustra suggested by this observation is, as in the proximal colon, that of increasing the surface for absorption, and not that of propelling the fecal matter.

The second method of propelling contents in the distal colon has been reported by Fischl and Porges.[17] They saw a small piece about the size of the thumb separated from the mass in the transverse colon, and pushed slowly to and around the splenic flexure, then down the descending colon. Three or four similar masses followed the first, each new one starting as its predecessor came to a stop. Thus, either extensive accumulations of waste, or small fragments, can be transmitted toward the rectum.

In 1905, I reported, in a paper on auscultation of the alimentary canal,[18] having heard a progression of little crackling noises starting in the transverse colon and traceable from point to point along the distal portions of the large intestine. The progress is continuous and requires hardly a minute for its completion. It is likely to be followed by a tendency to pass gas from the bowel. Last year von Bergmann and Lenz reported seeing with the *x*-rays a superficial wave of contraction run along the transverse colon, and suggested that thus intestinal gases might be carried from the proximal to the terminal section of the intestine. Since the fermentative processes in the cecum and ascending portion

17. Fischl and Porges: München. med. Wchnschr., 1911, lviii, 2064.

18. Cannon: The Mechanical Factors of Digestion, London and New York, 1911, p. 176.

would be likely to cause a considerable production of gas in this region, a means of rapidly carrying it away is obviously advantageous. A similar rapid transport of material probably occurs when irritant products of putrefaction result in diarrhea.

Defecation.—The process of clearing the distal colon in the cat consists of a gradual reduction of the material present. First the tonic constrictions disappear, just as the haustral indentations disappear in man, and are replaced by a strong, broad contraction of the circular muscle, which separates proximal and distal masses. Simultaneously, a shortening of the descending colon pulls on the region of contraction and crowds material into the rectum. Now the broad contraction moves downward, and aided by muscles of the abdominal wall pushes the separated mass out of the canal. The colon then returns to its former position; but in about two hours, the remnant left in the colon is spread throughout the colon. Afterward the distal part of this mass is cut off and pushed out of the canal in the manner above described.

In man, the changes during defecation have been studied by the *x*-ray method by Hertz, Schwarz and others. As in the cat, a relatively long column of feces is passed out at one time. Hertz's tracings show that the entire large intestine below the splenic flexure is normally evacuated at a single act. And Schwarz has reported that at defecation the colon can clear itself from the ascending portion onward. The soft character of the final portion of a large fecal discharge would thus be accounted for. Again, as in the cat, so in man, the remnant left in the ascending colon is within a short time spread along the colon even to the end.[19]

According to Hertz the waste material accumulating in the distal colon in man normally stops at the junction between the pelvic colon and the rectum where an acute angle offers some obstruction to progress. Then from below upward the pelvic colon fills, and, if more material arrives, it gathers increasingly in the iliac and descending portions.

On becoming distended the pelvic colon rises and widens its acute angle with the rectum, thus removing the obstruction to the advancement of fecal matter. Some of this matter now entering the rectum leads to the

19. Schwarz: München. med. Wchnschr., 1911, lviii, 2063.

desire to defecate. The common performance of the act regularly after breakfast may be attributed, in part at least, to stimulation of peristalsis in the colon by taking food, aided perhaps by the muscular activities that attend arising and dressing. When the "desire to defecate" is not aroused by these natural events, voluntary contraction of the abdominal muscles may cause some feces to enter the rectum and thus evoke the call.

When the call to defecation has come, the further performance of the act is usually accomplished, but not necessarily, by increased intra-abdominal pressure—a result of voluntary contraction of the abdominal muscles —and by reflex contraction of the intestinal wall. As the diaphragm contracts, the entire transverse colon is pushed downward, and the ascending colon and cecum are forced into an almost globular form. The intra-abdominal pressure, as measured in the rectum during this stage, may be from four to eight times the normal, i. e., may be between 100 and 200 mm. of mercury.[20] This pressure causes more feces to enter and distend the rectum and anal canal. The distention of these parts arouses reflexes which start strong diastaltic contractions of the colon, continues the tendency to strain with the voluntary muscles, and produces relaxation of both anal sphincters.

The time required for a mass containing bismuth salts to pass through the alimentary canal has been variously given. According to Hertz the long way through the esophagus, stomach and small intestine is traversed in about four hours and a half. In a case carefully studied by Rieder material began to appear in the cecum in three hours and a half, and the small intestine was empty at the end of nine and a half hours. At least as much more time is required for the material to go along the relatively short distance from the cecum to the splenic flexure, four hours and a half, according to Hertz, and in Rieder's case about eleven hours. Defecation nine hours after breakfast (e. g., at 5 p. m. after an 8 o'clock morning meal) might, therefore, rid the body of waste taken in the same day. If the act were performed at 4 o'clock, however, this waste would not be discharged. And if 4 o'clock were the regular time for the act, the waste from breakfast must be retained for another twenty-four hours. Thus the interval between the taking of a meal

20. Keith: Allbutt and Rolleston's System of Medicine, 1907, iii, 860.

and the excretion of its residue may vary when the bowels are opened regularly once a day, between nine and thirty-two hours—the period depending on the time of eating and the time of defecation.

INNERVATION OF THE LARGE INTESTINE

The large intestine receives, like the stomach and small intestine, a double nerve-supply from the central nervous system—a tonic or motor supply through the sacral visceral nerves, and an inhibitory supply from the lumbar cord through the sympathetic system, by way of the inferior mesenteric ganglion. According to Elliott and Barclay-Smith the sacral visceral nerves do not innervate the proximal third of the colon in the cat or the cecum in the dog. Indeed, the regions of anastalsis seem not to receive motor impulses.

The functioning of the two sets of nerves is indicated by the results of sectioning, as well as by stimulating them. Severance of the sympathetic fibers in the cat and rabbit causes no lasting disturbance of the motor functions. After removal of the motor impulses, however, by destruction of the sacral cord or by cutting the nerves, feces accumulate and the contractions of the intestine are weak and sluggish.[21] These functional defects may be due to the persistence of inhibitory tonus, for when both sets of nerves are abolished in the dog, the animal, after a few weeks, exhibits normal activity of the colon, with feces of usual consistency discharged at customary intervals.

CONSTIPATION

As already stated, defecation is a reflex initiated by the presence of feces in the rectum. The section of sensory roots of the sacral nerves supplying the rectal mucosa causes an abolition of the normal coordination.[22] It is a matter of much practical importance that the rectal mucosa soon becomes adapted to the presence of a fecal accumulation, and then fails either to induce the desire to defecate or to initiate reflex contraction of the colon. If the call to defecation is not promptly obeyed, therefore, it ceases to be given, and the feces stagnate in the rectum.

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21. Elliott and Barclay-Smith: Jour. Physiol., 1904, xxxi, 288.
22. Merzbacher: Arch. f. d. ges. Physiol., 1900, lxxxi, 474.

Stagnation of feces in the rectum is only one of the ways in which passage of material through the alimentary canal may be delayed. In this form, for which Hertz has revived the name "dyschezia,"[23] the rate of movement through the entire length of the digestive tract, as far as the pelvis, may be normal, but the rectum and pelvic colon are not properly emptied. In other forms there may be delay somewhere in the long course which the food takes, because of inefficient motility, as in states of general atony, in depressive emotions, and in reflex inhibitions of intestinal movements. In still other cases the delay may be due to obstructions of various sorts. In distinguishing these various causes of delay in the passage of material through the alimentary canal, the *x*-ray method has provided a highly important aid to other methods of clinical examination.

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23. Hertz: Constipation and Allied Intestinal Disorders, London, 1909, p. 45.